16 CHLORINE

Because of the ubiquitous presence of Cl in soil and water, it did not receive much attention as a plant nutrient until 1954 when Broyer et al. (1954) offered convincing evidence for its essentiality. Chlorine as an element is a gas and is taken up by plants as the chloride ion (Cl^-). This is the form involved in most reactions in soil. In further discussion therefore chloride (Cl^-) is generally used.

Chloride has biochemical, as well as osmoregulatory, functions in plants. It is involved in the splitting of water molecules in photosystem II of photosynthesis (Izawa et al., 1969). Several enzymes such as ATPase, alpha-amylase, and asparagine synthetase require Cl^- for stimulation or activation. As regards osmoregulatory functions, when solutes such as Cl^- accumulate within a cell, a water potential gradient is developed across the cell wall causing more water to enter the cell. This leads to increased cell turgidity. If the cell of concern is a stomata, this process leads to stomatal opening when water moves into guard cells. Because Cl^- is very mobile and is tolerated at high concentrations, it is ideally suited to maintain charge balance when cations such as K^+ move across cell membranes (Fixen, 1993). The chloride requirement of plants for biochemical functions is hardly more than 100 mg kg^{-1} (plant dry matter). However, it is usually present in much higher concentrations (2000 to 20,000 mg kg^{-1}), suggesting a role in functions other than those of a biochemical nature.

16.1. CHLORINE IN SOILS

Chlorine occurs in soils as soluble salts such as NaCl, $CaCl_2$, and $MgCl_2$. Most Cl in soils has originated from salts trapped in parent material, marine aerosols, and volcanic emissions. The amount of Cl^- in soil solution ranges from 0.5 to 6×10^3 mg kg^{-1} soil; Cl^- is often the dominant anion in extracts of several saline soils.

16.2. ADDITION OF CHLORINE TO SOILS

Rain and irrigation waters, plus HCl released during volcanic eruptions and from marine aerosols, continuously add Cl to soil. Annual deposits in

rainwater vary from 15 to 40 kg ha^{-1} in the inlands and may be 100 kg ha^{-1} or more near a seacoast. Actual quantities of Cl in marine aerosols and rain water near a seacoast depends upon the foam formation on the top of waves, the velocity of wind sweeping inland from the sea, temperature, topography of the coastal region, and the amount, frequency, and intensity of rainfall. Salty droplets or dry salt dust may be whirled to great heights by strong air currents and carried over large distances toward the inlands (Tisdale et al., 1985). Irrigation water can also add large amounts of Cl to soil.

16.3. TESTING SOILS FOR CHLORINE DEFICIENCY

Water-soluble Cl in the soil to a depth of 60 cm is a good indicator of Cl availability (James et al., 1970). In one of the most extensive evaluations of soil Cl, field trials were conducted at 36 locations in 5 years across South Dakota using spring-wheat cultivars known to be Cl responsive. A critical level of 43 kg Cl ha^{-1} divided 83% of the sites into low Cl responsive or high Cl nonresponsive quadrants (Figure 16.1) (Fixen, 1987). In general, the magnitude of response to Cl is on the average more limited than responses to macronutrients.

16.4. CHLORINE DEFICIENCY SYMPTOMS

As in the case of other elements, deficiency symptoms of Cl differ from crop to crop. The common symptoms characteristic of Cl deficiency are wilting of the leaf blade tips followed by chlorosis, bronzing, and necrosis. Restricted root growth with stubby, club-tipped laterals is also characteristic of Cl deficiency. In barley, leaves may remain wrapped in tubular form longer than normal, have slower growth, and become more fragile than normal leaves. In potatoes, leaves become lighter green in color and give a pebbled appearance (vertical protrusions on the upper side of leaflets). Coconut palm (*Cocus mucifera* L.) trees deficient in Cl have older leaves with yellowing and/or orange mottling and dried up leaf tips and edges (von Uexkull and Sanders, 1986).

16.5. CHLORINE TOXICITY SYMPTOMS

Excess Cl in soil and its toxic effects on plants have received more attention than Cl deficiency. The primary influence of high Cl concentration in soil solution is increased osmotic pressure of soil water, resulting in reduced availability of water to plants and consequent wilting (Cl-induced drought). Most fruit trees, berry and vine crops, and ornamental shrubs are specifically sensitive to Cl ions and develop leaf-burn symptoms when Cl concentration in plants reaches about 0.5% (on dry matter basis) (Tisdale et al., 1985). Thickening and rolling in tobacco and tomato leaves may occur.

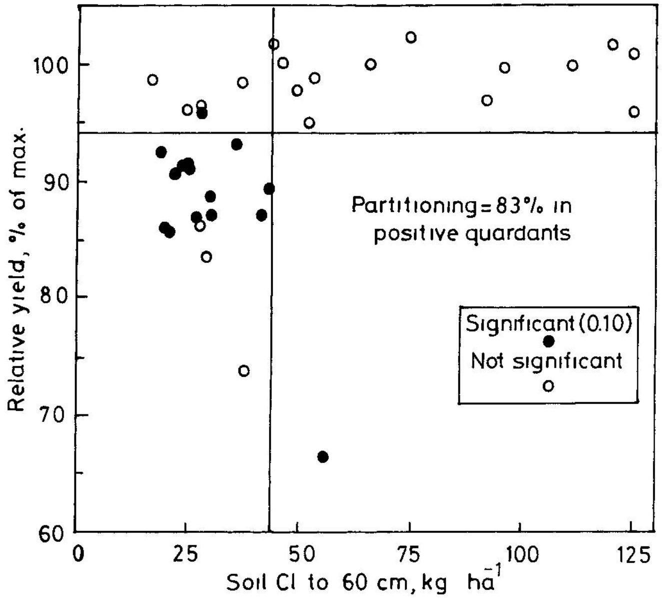

Figure 16.1. Influence of soil Cl content on relative grain yield of spring wheat. (From Fixen, 1987. Crops Soils 39:14–16. With permission.)

16.6. INTERACTIONS WITH OTHER NUTRIENTS

Uptake of Cl is competitively inhibited by NO_3^- and sulfate. Irrigated hard red spring wheat in Montana inoculated with take-all fungus (*Gaeumannomyces graminis* var *tritici*) responded to Cl fertilization when NH_4^+-N was applied and not when NO_3^--N was applied (Engel and Mathre, 1988). Nitrate and Cl^- compete with each other for uptake in potatoes, sugarbeets, tomatoes, beans, tobacco, barley, and wheat (Fixen, 1993). For example, in barley the net accumulation of Cl was virtually eliminated in roots and reduced by 40% in shoots when external media (0.5 mol m^{-3} $CaSO_4$ plus 0.5 mol m^{-3} KCl) were supplemented with 0.25 mol m^{-3} $Ca(NO_3)_2$ (Table 16.1) (Glass and Siddiqi, 1985).

Chloride inhibits nitrification in acid soils; concentrations of 46 to 152 mg Cl^- kg^{-1} soil are required for measurable inhibitions of nitrification. Such high concentrations of Cl^- can be encountered in saline soils. For example, Christensen and Brett (1985) showed that the NH_4^+-N:NO_3^--N ratio remained above 3:1 for 12 days longer with NH_4Cl than with $(NH_4)_2SO_4$ at pH 5.5. This nitrification-inhibiting property of Cl^- was not observed when soil pH was raised to 6.6 by liming.

Chloride appears to interact with P in a complex and largely unknown manner. In some cases P availability is increased by elevating Cl^-, while in other cases it is not affected or decreases (Fixen, 1993).

Table 16.1 Chloride and Nitrate Concentrations of Roots and Shoots as a Function of Nitrate and Chloride Provision[a]

Nitrate/Chloride provision in growth medium (mol m^{-3})		Ion content of tissues (μmol g^{-1})			
		Cl^-		NO_3^-	
KCl	$Ca(NO_3)_2$	Root[b]	Shoot	Root	Shoot
0.0	0.0	114	21	6	23
0.5	0.0	45	88	3	17
0.5	0.0625	17	57	55	57
0.5	0.125	17	60	58	64
0.5	0.25	15	53	62	70
0.5	0.5	15	52	68	76
0.5	1.0	12	50	73	78
1.0	0.0	52	93	8	21
1.0	0.1	26	73	45	50
1.0	0.5	13	59	73	79
1.0	1.0	11	58	78	89
1.0	2.5	9	46	78	97
1.0	5.0	9	46	81	99
1.0	10.0	8	40	84	107

[a] Nutrients were completely replaced twice daily.

[b] Standard errors of the means were generally within 2% of the means.

Adapted from Glass and Siddiqi (1985).

Application of KCl increases Mn release from soils and its uptake by plants, which may reach toxic levels. In a study in Oregon on a poorly drained soil with pH 4.7 to 5.3 and with appreciable Mn concentrations in its profile, Cl application increased Mn uptake of bush beans (Table 16.2) and sweet corn and resulted in Mn toxicity symptoms in beans (Jackson et al., 1966). Mn toxicity has been offered as a possible explanation for the yield reductions on acidic soils observed from band application of KCl at planting.

16.7. CHLORIDES AND PLANT DISEASES

Chloride application is reported to suppress or reduce the effects of numerous diseases on a variety of crop species. Some of these are listed in Table 16.3.

16.8. CROP RESPONSES TO CHLORIDE FERTILIZATION

Extensive Cl research has been conducted on wheat and barley in the northwestern United States and the Great Plains of North America. Responses in the Great Plains have generally been modest compared with those measured

Table 16.2 The Effect of Additions of Lime and KCl on the Mn Content in Recently Matured Trifoliate Leaves and Yield of Bush Beans (*Phaseolus vulgaris*)

	No lime		6.72 Mg lime ha^{-1}	
kg K ha^{-1}	mg Mn kg^{-1} DM	Grain Mg ha^{-1}	mg Mn kg^{-1} DM	Grain Mg ha^{-1}
0	798	11.5	528	8.09
55.5	1190	5.8	772	15.7
111	1048	4.6	610	13.8
LSD (P = 0.05)				
Lime at constant K	458	3.7		
K at constant lime	482	4.7		

Adapted from Jackson et al. (1966).

Table 16.3 Plant Disease with Reported Suppression Using Cl Fertilizers

Crop	Diseases
Winter wheat	Take-all root rot, tan spot, stripe rust, Septoria, leaf rust
Spring wheat	Common root rot, tan spot, leaf rust, Septoria
Barley	Common root rot, Fusarium root rot, spot blotch
Durum wheat	Common root rot
Corn	Stalk rot
Pearl millet	Downy mildew
Coconut palm	Gray leaf spot
Potatoes	Hollow heart, brown center
Celery	Fusarium yellows
Rice	Stem rot, sheath blight

Adapted from Fixen (1987).

in the northwestern United States. The results from the Great Plains are shown in Figure 16.2. There appears to be less potential for corn to benefit from Cl fertilization as compared with other cereal crops (Fixen, 1993).

Coconut and oil palms respond markedly to Cl fertilization on low Cl soils, typically occurring at distances greater than 20 to 25 km from the sea (von Uexkull and Sanders, 1986; Ollagnier and Olivin, 1984).

16.9. CHLORIDE FERTILIZERS

Potassium chloride (47% Cl), ammonium chloride (66% Cl), calcium chloride (65% Cl), magnesium chloride (74% Cl), and sodium chloride (66% Cl) are the most common chloride fertilizers.

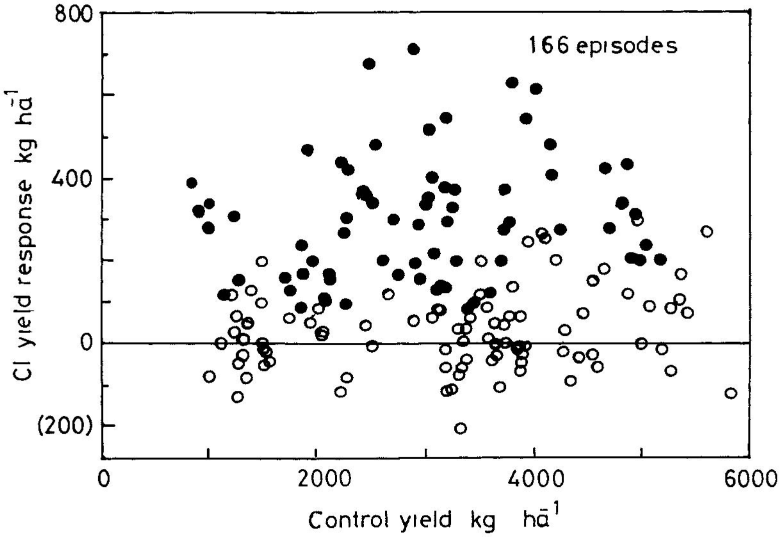

Figure 16.2. Chloride yield response relative to control yields in the Great Plains. s, **Nonsignificant;** d, **significant (>67 kg ha^{-1}). Each data point represents a cultivar × site × year episode. (From Engel et al., 1992. Proceedings of the Great Plains Soil Fertility Conference, 4:232–241. With permission of Kansas State University, Manhattan, KS.**

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